

## WHAT IS CLAIMED IS:

1. A numerical calculation method for a physical quantity  $U$  practiced on a computer by solving  $A \cdot U = f$ , wherein  $A$  is a coefficient matrix (in  $N$  rows by  $N$  columns; wherein  $N$  is a positive integer) obtained through discrete of a partial differential equation to be satisfied by said physical quantity  $U$ , and  $f$  is an inhomogeneous term (source term), comprising the processes of:

setting an initial value  $U^0$  of said physical quantity  $U$ ;

setting 0 as an initial value of a number  $m$  of repeating times, giving 0 as an initial value of a perturbation quantity  $\phi$  and setting  $(f - A \cdot U^0)$  as an initial value  $r^0$  of a residual  $r$ ; and

repeatedly executing a first step and a second step while incrementing said number  $m$  of repeating times until an approximate solution  $U^m$  is converged,

wherein said first step includes the steps of:

obtaining a predicted approximate value  $\psi^m$  of  $A \cdot \phi = r^m$  through repeated calculation performed by a first calculation unit including an internal solver, and

said second step includes the steps of:

obtaining, from said predicted approximate value  $\psi^m$ , a corrected approximate value  $\phi^m$  for minimizing  $L^2$  norm of a residual  $r^m$  through an optimization routine performed by a second calculation unit; and

giving  $(U^m + \phi^m)$  as an approximate solution  $U^{m+1}$  and giving  $(r^m - A \cdot \phi^m)$  as a residual  $r^{m+1}$ ,

wherein in said second step, obtained elements of a vector sequence  $A \cdot \phi^m$  are sampled by a given sampling method to be stored in a memory, and

a residual minimization coefficient  $\alpha_l^m$  (wherein  $l = 1, \dots, L$ ) used for obtaining said corrected approximate value  $\phi^m$  is approximately obtained by using elements of a

vector sequence  $A \cdot \phi^k$  (wherein  $k = m - L + 1, \dots, m - 1$ ) stored in said memory.

2. The numerical calculation method of Claim 1,

wherein in sampling of elements  $b_1, b_2, \dots$  and  $b_N$  of said vector sequence  $A \cdot \phi^m$  performed in said second step, elements  $b_i$  (wherein  $i \in \Omega$ ) are selected, whereas a subset  $\Omega$  is defined as follows:

$$\Omega = \{i : \text{mod}[i, lg] = 1\} \cup \{i : |f_i/a_{ii}| > \beta\}$$

wherein  $lg$  is an integer,  $\beta$  is a real number,  $f_i$  is an element of said source term and  $a_{ii}$  is a diagonal term on the  $i$ th row in the  $i$ th column of said matrix  $A$ .

3. A numerical calculator for a physical quantity  $U$  by solving  $A \cdot U = f$ , wherein  $A$  is a coefficient matrix (in  $N$  rows by  $N$  columns; wherein  $N$  is a positive integer) obtained through discrete of a partial differential equation to be satisfied by said physical quantity  $U$ , and  $f$  is an inhomogeneous term (source term), performing the processes of:

setting an initial value  $U^0$  of said physical quantity  $U$ ;

setting 0 as an initial value of a number  $m$  of repeating times, giving 0 as an initial value of a perturbation quantity  $\phi$  and setting  $(f - A \cdot U^0)$  as an initial value  $r^0$  of a residual  $r$ ; and

repeatedly executing a first step and a second step while incrementing said number  $m$  of repeating times until an approximate solution  $U^m$  is converged,

wherein said first step includes the steps of:

obtaining a predicted approximate value  $\psi^m$  of  $A \cdot \phi = r^m$  through repeated calculation performed by a first calculation unit including an internal solver, and

said second step includes the steps of:

obtaining, from said predicted approximate value  $\psi^m$ , a corrected approximate value  $\phi^m$  for minimizing  $L^2$  norm of a residual  $r^m$  through an optimization routine

performed by a second calculation unit; and

giving  $(U^m + \phi^m)$  as an approximate solution  $U^{m+1}$  and giving  $(r^m - A \cdot \phi^m)$  as a residual  $r^{m+1}$ ,

wherein in said second step, obtained elements of a vector sequence  $A \cdot \phi^m$  are sampled by a given sampling method to be stored in a memory, and

5 a residual minimization coefficient  $\alpha_l^m$  (wherein  $l = 1, \dots, L$ ) used for obtaining said corrected approximate value  $\phi^m$  is approximately obtained by using elements of a vector sequence  $A \cdot \phi^k$  (wherein  $k = m - L + 1, \dots, m - 1$ ) stored in said memory.

4. The numerical calculator of Claim 3,

wherein in sampling of elements  $b_1, b_2, \dots$  and  $b_N$  of said vector sequence  $A \cdot \phi^m$   
10 performed in said second step, elements  $b_i$  (wherein  $i \in \Omega$ ) are selected, whereas a subset  $\Omega$  is defined as follows:

$$\Omega = \{i : \text{mod}[i, \lg] = 1\} \cup \{i : |f_i/a_{ii}| > \beta\}$$

wherein  $\lg$  is an integer,  $\beta$  is a real number,  $f_i$  is an element of said source term and  $a_{ii}$  is a diagonal term on the  $i$ th row in the  $i$ th column of said matrix  $A$ .

15 5. A recording medium that stores a numerical calculation program for a physical quantity  $U$  by allowing a computer to solve  $A \cdot U = f$ , wherein  $A$  is a coefficient matrix (in  $N$  rows by  $N$  columns; wherein  $N$  is a positive integer) obtained through discrete of a partial differential equation to be satisfied by said physical quantity  $U$ , and  $f$  is an inhomogeneous term (source term),

20 wherein said numerical calculation program makes said computer to execute the processes of:

setting an initial value  $U^0$  of said physical quantity  $U$ ;

setting 0 as an initial value of a number  $m$  of repeating times, giving 0 as an initial value of a perturbation quantity  $\phi$  and setting  $(f - A \cdot U^0)$  as an initial value  $r^0$  of a

25 residual  $r$ ; and

repeatedly executing a first step and a second step while incrementing said number  $m$  of repeating times until an approximate solution  $U^m$  is converged,

wherein said first step includes the steps of:

obtaining a predicted approximate value  $\psi^m$  of  $A \cdot \phi = r^m$  through repeated

5 calculation performed by a first calculation unit including an internal solver, and

said second step includes the steps of:

obtaining, from said predicted approximate value  $\psi^m$ , a corrected approximate value  $\phi^m$  for minimizing  $L^2$  norm of a residual  $r^m$  through an optimization routine performed by a second calculation unit; and

10 giving  $(U^m + \phi^m)$  as an approximate solution  $U^{m+1}$  and giving  $(r^m - A \cdot \phi^m)$  as a residual  $r^{m+1}$ ,

wherein in said second step, obtained elements of a vector sequence  $A \cdot \phi^m$  are sampled by a given sampling method to be stored in a memory, and

a residual minimization coefficient  $\alpha_l^m$  (wherein  $l = 1, \dots, L$ ) used for obtaining  
15 said corrected approximate value  $\phi^m$  is approximately obtained by using elements of a vector sequence  $A \cdot \phi^k$  (wherein  $k = m - L + 1, \dots, m - 1$ ) stored in said memory.

6. The recording medium of Claim 5,

wherein in sampling of elements  $b_1, b_2, \dots$  and  $b_N$  of said vector sequence  $A \cdot \phi^m$  performed in said second step, elements  $b_i$  (wherein  $i \in \Omega$ ) are selected, whereas a subset  $\Omega$   
20 is defined as follows:

$$\Omega = \{i : \text{mod}[i, \lg] = 1\} \cup \{i : |f_i/a_{ii}| > \beta\}$$

wherein  $\lg$  is an integer,  $\beta$  is a real number,  $f_i$  is an element of said source term and  $a_{ii}$  is a diagonal term on the  $i$ th row in the  $i$ th column of said matrix  $A$ .